

# STRENGTH OF SOME ENGINEERING MATERIALS

Material code	MPa	
	$\sigma_u$	$\sigma_y$
CG 18	180	
CG 22	220	
CG 26	260	
CG 30	300	
CG 40	400	250
GT 40	400	220
GT 35	350	200
GS 38	380	180
GS 45	450	220
GS 52	520	250
GS 60	600	360
St 34	340	190
St 37	370	200
St 42	420	220
St 50	500	250
St 60	600	300
St 70	700	340

Material code	MPa	
	$\sigma_u$	$\sigma_y$
St 10	420	250
St 15	500	300
St 15 Cr 3	600	400
St 16 Mn Cr 5	800	600
St 18 Cr Ni 8	1200	800
St 22	550	300
St 35	600	370
St 45	660	400
St 60	750	490
St 30 Mn 5	800	550
St 37 Mn Si 5	900	600
St 42 Cr Mo 4	980	760
St 36 Cr Ni Mo 1	1000	900
St 34 Cr Ni Mo 6	1100	900
St 30 Cr Ni Mo 8	1250	1050

		GPa	MPa	
		E	$\sigma_u$	$\sigma_y$
Copper	Cu 720	120	200	120
Brass	Cu Zn20 P35	119	320	200
	Cu Zn37 P45	110	440	370
	Cu Zn39 Pb3 P44	93	430	250
Bronze	Cu Sn6 P41	110	400	200
	Cu Sn12	93	260	140

$1 \text{ kg/cm}^2 \approx 0.1 \text{ MPa}$   
 $1 \text{ N/mm}^2 = 1 \text{ MN/m}^2 = 1 \text{ MPa}$   
 $1 \text{ MPa} = 10^6 \text{ Pa}$   
 $1 \text{ GPa} = 10^9 \text{ Pa}$

## COEFFICIENT OF FRICTION

	Dry	Lubricated
Steel / Steel	0.15-0.25	0.11-0.17
Steel / Brass	0.15-0.25	0.10-0.16
Steel / Cast Iron	0.15-0.25	0.10-0.17
Cast Iron / Cast Iron	0.20-0.25	0.10-0.05

## BEARING PRESSURES AT LOW ROLLING SPEED AND LOW WORKING TEMPERATURE

Cast Iron / Steel  $p = 12 \text{ MPa}$   
 Brass / Steel  $p = 17 \text{ MPa}$   
 Steel / Steel  $p = 15 \text{ MPa}$

## High Tensile Steel Bolts

Nominal Size	Pitch	Core Area  mm <sup>2</sup>	Breaking Stress (Kg/cm <sup>2</sup> X 10 <sup>-3</sup> )									
			3.6	4.6	4.8	5.6	5.8	6.8	8.8	9.8	10.9	12.9
			Max. Allowed Load, N									
mm.	mm.	mm <sup>2</sup>										
8	1	39.2	7060	8820	12200	11000	14900	17200	22700	25500	32500	38000
10	1.25	61.2	11000	13800	19000	17100	23300	26900	35500	39800	50800	59400
12	1.25	92.1	16600	20700	28600	25800	35000	40500	53400	59900	76400	89300
14	1.5	125	22500	28100	38800	35000	47500	55000	72500	81200	104000	121000
16	1.5	167	30100	37600	51800	46800	63500	73500	96900	109000	139000	162000
18	1.5	216	38900	48600	67000	60800	82100	95000	130000	—	179000	210000

Properties of Materials

Material	DIN	Abbreviated name (DIN 17 006)	Primary alloying constituents, mean values in % by wt.	$R_m^{(1)}$ min. N/mm <sup>2</sup>	$R_p^{(2)}$ min. N/mm <sup>2</sup>	$A_5^{(3)}$ min. %	$\sigma_{bw}^{(4)}$ min. N/mm <sup>2</sup>	$\tau_w^{(5)}$ min. N/mm <sup>2</sup>	Properties, typical applications
<b>Cast Iron and Malleable Cast Iron</b> $E$ in $10^3$ N/mm <sup>2</sup> for GG-15 <sup>6</sup> ) $\approx$ 79, GG-25 <sup>6</sup> ) $\approx$ 121, GTW and GTS $\approx$ 175									
Gray cast iron	1691	GG-15	3.5 C; 2.1 Si; 0.6 Mn; 0.7 P	150	—	—	70	50	Brittle, good machinability
		GG-25	3.0 C; 1.4 Si; 0.8 Mn; <0.3 P	250	—	—	120	90	
Modular cast iron	1693	GGG-40	3.6 C; 2.8 Si; 0.4 Mn	400	250	15	200	140	Good machinability, heat-treatable
Malleable cast iron	1692	GTW-40	3.1 C; 0.6 Si; 0.4 Mn; 0.2 S	400	220	5	190	140	Good machinability, tough.
		GTS-35	2.5 C; 1.3 Si; 0.4 Mn; 0.1 S	350	200	12	170	125	

Steel (Modulus of elasticity in tensions or compression  $E \approx 206\,000$  N/mm<sup>2</sup>)

Free cutting steel (16 ... 40 mm dia.)	1651	9 SMn 28 K 35 S 20 K	$\leq 0.14$ C; 1.1 Mn; 0.28 S 0.35 C; 0.7 Mn; 0.2 S	460	375	8	—	—	Case-hardenable, heat-treatable.
				540	315	8	—	—	
Strip and sheet of mild unalloyed steels	1623	St 12	$\leq 0.1$ C; $\leq 0.007$ N	<410	<280	28	—	—	Simple deep-drawn parts. Difficult deep-drawn parts. Complex deep-drawn parts.
		St 13	$\leq 0.1$ C; $\leq 0.007$ N	<370	<250	32	—	—	
		St 14	$\leq 0.08$ C; $\geq 0.02$ Al	<350	<220	36	—	—	
Structural steel (rolled)	17 100	St 37-2	0.17 C	340	235	25	170	95	Low-stressed parts. Higher-stressed parts.
		St 60-2	0.40 C	570	335	15	280	160	
Case-depth steel (case hardness >0.7 mm, core hardened, 11 mm dia.)	17 210	Ck 15	0.15 C; 0.45 Mn; 0.25 Si	Hardness (min.): Surface 700 HV Core 235 HV		—	—	—	Simple components.  Gears and similar components. Gears and similar components. Parts subject to impact loading.
		16 MnCr5	0.16 C; 1.15 Mn; 1 Cr	Surface 700 HV Core 280 HV		—	—	—	
		20 MoCr4	0.2 C; 0.75 Mn; 0.4 Cr; 0.45 Mo	Surface 700 HV Core 280 HV		—	—	—	
		15 CrNi6	0.15 C; 0.5 Mn; 1.5 Cr; 1.5 Ni	Surface 700 HV Core 300 HV		—	—	—	

Cemented carbides	—	—	W (Ti, Ta)-carbide + Co	800 ... 1800 HV	Sintering materials, extreme resistance to pressure and wear, but brittle; cutting tools, blanking dies and metalforming dies.	
Nitriding steel (quenched and tempered, nitrieded)	17 211	34 CrAlMo 5	0.35 C; 1 Al; 1.15 Cr; 0.2 Mo	780   590   14 Surface hardness ≈ 950 HV	—	Good wear resistance
Stainless steel	17 440	X 5 CrNi 189	≤ 0.07 C; 18 Cr; 9 Ni	500   185   45 Hardness ≥ 130 HV	—	Corrosion-resistant, non-magnetic, not hardenable
High-speed steel	—	S 6-5-2	0.8 C; 5 W; 5 Mo; 2 V	63 ... 65 HRC	Wear-resistant at high temperature, for universal use, twist drills, milling cutters, extrusion dies	
Cast steel	1681	GS-45	≤ 0.25 C; 0.6 Si	450   230   22	210   140	Heat-treatable
Heat-treatable steel (quenched and tempered, 16 ... 40 mm dia.)	17 200	Ck 45 42 CrMo 4 30 CrNiMo 8	0.45 C; 0.65 Mn; 0.25 Si 0.4 C; 0.65 Mn; 1 Cr; 0.2 Mn 0.3 C; 2 Cr; 0.4 Mo; 2 Ni	660   410   16 980   765   11 1230   1030   9	325   185 480   275 590   345	Highly stressed parts Very highly stressed parts Very highly stressed parts
Roller-bearing steel (hardened, tempered)	—	100 Cr 6	1 C; 0.3 Mn; 0.25 Si; 1.5 Cr	Hardness ≥ 60 HRC	—	Wear-resistant
Tool steel	—	C 80 W 1 115 Cr V 5 21 MnCr 5 90 MnV 8 X 210 CrW 12 X 40 CrMoV 51	0.8 C 1.15 C; 0.7 Cr; 0.1 V 0.2 C; 1.3 Mn; 1.2 Cr 0.9 C; 2 Mn; 0.1 V 2.1 C; 12 Cr; 0.7 W 0.4 C; 5 Cr; 1 Mo; 1 V	Standard hardness values: 60 ... 63 HRC 60 ... 63 HRC  Surface 60 HRC, Core 32 HRC 60 ... 63 HRC  60 ... 63 HRC 43 ... 45 HRC	Water-hardening steel: simple dies. Water/oil-hardening steel; twist drills, taps, metal saws, punches. Case-hardening steel; molds for plastics  Oil-hardening steel; blanking dies, stamping and deep-drawing dies, cutting tools, molds for plastics and rubber, taps. Oil and air-hardening steels, super-high wear resistance; blanking and drawing dies Hot work tool steel; for general use	

1) Tensile strength  
2) Yield point (or  $R_p$ ).  
3) Elongation after fracture.

4) Fatigue limit under rotary bending stresses (in the case of steel, fatigue limit under flat reversed bending stress  $\approx 0.8 \times$  fatigue limit under rotary reversed bending stress).

5) Fatigue limit under reversed torsional stresses.  
6) For gray cast iron,  $E$  decreases with increasing tensile stress, but remains almost constant with increasing compression stress. The data given applies for a tensile stress of 10 ... 80 N/mm<sup>2</sup>.

Steel (continued)  
Spring steel

Materials	DIN	Nominal composition, % by wt.	Diameter in mm	$R_m^{1)}$ min. N/mm <sup>2</sup>	$Z^2)$ %	$\sigma_b^{3)}$ N/mm <sup>2</sup>	$\tau_{th}^{4)}$ N/mm <sup>2</sup>	$\tau_{perm}^{5)}$ N/mm <sup>2</sup>	Characteristic properties, applications
(1) Spring steel strip Ck 85 <sup>6)</sup>	17 222	0.85 C; 0.55 Mn; 0.25 Si	$h \leq 2.5$	1470	—	1270	$\sigma_{bh} = 640$	—	Highly-stressed leaf springs
(2) Spring steel wire C, patented, drawn <sup>6)</sup> (Music wire)	17 223 Sheet 1	0.8 C; 0.6 Mn; < 0.35 Si	1 3 10	2230 1840 1350	40 40 30	1590 1280 930	320 <sup>7)</sup> 320 <sup>7)</sup> 320 <sup>7)</sup>	1115 920 675	For high maximum stresses (see. p. 230)
(3) Stainless steel spring wire	17 224	< 0.12 C; 17 Cr; 7.5 Ni	1 3	2000 1600	40 40	1400 1130	—	1000 800	Stainless steel springs
(4) Stainless steel spring strip	17 224	< 0.12 C; 17 Cr; 7.5 Ni	$h \leq 1$	1370	—	1230	$\sigma_{bh} = 590$	—	Stainless steel leaf springs
(5) Oil-tempered valve-spring wire	17 223 Sheet 2	0.65 C; 0.7 Mn; $\leq 0.30$ Si	1 3 8	1720 1480 1390	45 45 38	1200 1040 930	380 <sup>8)</sup> 380 <sup>8)</sup> 360 <sup>9)</sup>	860 740 690	For severe fatigue loading
(6) Oil-tempered (Cr-Si valve-spring wire)	—	0.55 C; 0.7 Mn; 0.65 Cr; 1.4 Si	1 3 8	2060 1920 1720	50 50 40	— — —	430 430 380	1030 960 860	For most severe fatigue loading and high temperatures
(7) Oil-tempered (Cr-V valve-spring wire)	—	0.7 C; 0.7 Mn; 0.5 Cr; 0.15 V; $\leq 0.30$ Si	1 3 8	1860 1670 1420	45 45 40	— — —	470 470 400	930 835 710	For most severe fatigue loading

<sup>1)</sup> Tensile strength. <sup>2)</sup> Reduction of area at fracture. <sup>3)</sup> Permissible bending stress. <sup>4)</sup> Permissible stress range. <sup>5)</sup> Permissible maximum stress. <sup>6)</sup> See pp. 230 and 231 for fatigue-strength diagrams. <sup>7)</sup> 400 N/mm<sup>2</sup> for peened springs. <sup>8)</sup> 500 N/mm<sup>2</sup> for peened springs.

Vehicle Body Sheet Metal

Abbreviated material name	Standard material thicknesses mm	$R_{p0.2}^{1)}$ N/mm <sup>2</sup>	$R_m^{2)}$ N/mm <sup>2</sup>	$A_{80}^{3)}$ %	Properties, typical applications
St 12	0.6 ... 2.5	≈ 250	≈ 340	≈ 30	For simple drawn metal parts
St 13		≈ 225	≈ 320	≈ 35	For complicated drawn metal parts
St 14		≈ 200	≈ 300	≈ 40	For very complex deep drawn parts, outer body parts (roof, doors, fenders, etc.; 0.75 ... 1.0 mm); see also DIN 1623
ZE 260	0.75 ... 2.0	260 ... 340	≈ 370	≈ 28	For highly-stressed, load-bearing beams whose forming is not too complicated
ZE 340		340 ... 420	≈ 420	≈ 24	
AlMg 0.4 Si 1.2	0.8 ... 2.5	≈ 140	≈ 250	≈ 28	For outer body parts such as front fenders, doors, hood, trunk lid, etc.; usually 1.25 mm; see DIN 1745
AlMg 4.5 Mn 0.3	0.5 ... 3.5	≈ 130	≈ 270	≈ 28	For inner reinforcements of hinged covers; for parts which are not visible; stretcher strains are acceptable

<sup>1)</sup> Proof stress (non-proportional elongation). <sup>2)</sup> Tensile strength. <sup>3)</sup> Percentage elongation after fracture.

Nonferrous Metals

Material	DIN	Designation	Nominal composition, mean values % by wt.	E <sup>1)</sup> N/mm <sup>2</sup>	R <sub>m</sub> <sup>2)</sup> min. N/mm <sup>2</sup>	R <sub>p0.2</sub> <sup>3)</sup> min. N/mm <sup>2</sup>	σ <sub>bw</sub> <sup>4)</sup> min. N/mm <sup>2</sup>	Properties, typical applications
<b>Heavy Metals</b>								
High-conductivity copper	1787	E-Cu 57 F 20	99.90 Cu	128 x 10 <sup>3</sup>	200	120 <sup>5)</sup>	70	Very good electrical conductivity
Brass	17 660	CuZn 20 F 32	80 Cu; 20 Zn	119 x 10 <sup>3</sup>	320	200	110	Deep-drawn parts
		CuZn 37 F 44	63 Cu; 37 Zn	110 x 10 <sup>3</sup>	440	370	140	Good cold-formability
		CuZn 39 Pb 3 F 43	58 Cu; 39 Zn; 3 Pb	96 x 10 <sup>3</sup>	430	250	150	Free-cutting brass
Nickel silver	17 663	CuNi 12 Zn 24 F 43	64.5 Cu; 23.5 Zn; 12 Ni	125 x 10 <sup>3</sup>	430	230	—	Corrosion-resistant
Tin bronze	17 662	CuSn 6 F 41	94 Cu; 6 Sn	118 x 10 <sup>3</sup>	410	300	175	Good antifriction features; bearing bushes, springs
Cast tin bronze	1705	G-CuSn 12	86 Cu; 12 Sn	100 x 10 <sup>3</sup>	260 <sup>6)</sup>	140 <sup>6)</sup>	90	Corrosion-resistant; wear-resistant; gears
	1705	G-CuSn 5 ZnPb	85 Cu; 5 Sn; 5 Zn; 5 Pb	85 x 10 <sup>3</sup>	220 <sup>6)</sup>	90 <sup>6)</sup>	75	Corrosion-resistant
Red brass								
Commercial lead Hard lead	1719		99.9 Pb	17 x 10 <sup>3</sup>	10	—	2	Soft, acid-resist.; seals
	17 641	PbSb 5	94 Pb; 6 Sb		30	—	—	Acid-resistant; fittings, battery plates
Lead diecastings	1741	GD-Pb 87 Sb	87 Pb; 13 Sb		60	—	—	Dimensionally accurate cen- trifugal and balance weights
Tin alloy	1703	LgSn 80	80 Sn; 12 Sb; 6 Cu; 2 Pb	30 x 10 <sup>3</sup>	80	—	—	Plain bearings
Zink diecastings	1743	GD-ZnAl4	96 Zn; 4 Al	128 x 10 <sup>3</sup>	250	200	60	Dimensionally accurate castings
Heating-element alloy	17 470	NiCr 80 20	80 Ni; 20 Cr	—	600	300	—	High electrical resistance (See p. 175)
	17 743	NiCu 30 Al	64 Ni; 31 Cu; 3 Al; 1 Fe; 1 Ti	—	680	360	—	
Resistance alloy	17 471	CuNi 44	55 Cu; 44 Ni; 1 Mn	—	420	—	—	
		CuNi 30 Mn	67 Cu; 30 Ni; 3 Mn	—	400	—	—	
		CuMn 12 NiAl	82 Cu; 12 Mn; 5 Ni; 1 Al	—	400	—	—	

1) Modulus of elasticity, reference values. 2) Tensile strength. 3) Yield strength (0.2% offset). 4) Bending fatigue limit. 5) Maximum.  
6) For separately cast test specimen.

Light metals

Material	Nominal composition, mean values % by wt.	$R_m^{1)}$ min. N/mm <sup>2</sup>	$R_{p0.2}^{2)}$ min. N/mm <sup>2</sup>	$\sigma_{bw}^{3)}$ min. N/mm <sup>2</sup>	Properties, typical applications
Wrought Aluminum Alloys (DIN 1712, 1725, 1745 ... 1749, 40501), modulus of elasticity $E \approx 70,000$ N/mm <sup>2</sup>					
Al99.5W7	99.5 Al	65	55 <sup>4)</sup>	40	Soft, good conductor, can be anodized/polished; Resistant to sea water, can be anodized Precipitation hardened, resistant to sea water Precipitation hardened, good creep properties Maximum strength
AlMg2Mn0.8W19	97 Al; 2 Mg; 0.8 Mn	190	80	90	
AlMgSi1F28	97 Al; 0.9 Mg; 1 Si; 0.7 Mn	275	200	90	
AlCuMg1F40	94 Al; 4 Cu; 0.7 Mg; 0.7 Mn; 0.5 Si	395	265	120	
AlZnMgCu1.5F53	90 Al; 6 Zn; 2 Mg; 2 Cu; 0.2 Cr	530	450	140	
Cast-Aluminum Alloy <sup>5)</sup> (DIN 1725, Part 2), modulus of elasticity $E \approx 70,000$ N/mm <sup>2</sup>					
GK-ALSi12	88 Al; 12 Si; 0.2 Mn	180	90	70	Thin-walled parts with good fatigue strength Sea-water resistant; can be anodized/polished Precipitation hardened; highly-stressed parts with good fatigue strength Precipitation hardened; highly-stressed parts Precipitation hardened; simple parts to meet maximum strength and toughness requirements Good thermal strength; complex diecastings Sea-water resistant; medium-stressed parts.
GK-ALMg5Si	94 Al; 5 Mg; 1 Si; 0.2 Mn; 0.1 Ti	180	110	70	
GK-ALSi10Mgwa	89 Al; 10 Si; 0.4 Mg; 0.2 Mn	240	210	100	
GK-ALSi5Mgwa	94 Al; 5 Si; 0.6 Mg; 0.2 Mn; 0.1 Ti	260	240	80	
GK-ALCu4Tawa	95 Al; 5 Cu; 0.2 Ti	330	220	90	
GD-ALSi8Cu3	88 Al; 8 Si; 3 Cu; 0.4 Mn; 0.2 Mg	240	150	70 <sup>6)</sup>	
GD-ALMg9	90 Al; 9 Mg; 1 Si; 0.4 Mn	200	140	55 <sup>6)</sup>	
Magnesium Alloy (DIN 1729, 9715), modulus of elasticity $E \approx 45,000$ N/mm <sup>2</sup>					
MgAl6ZnF27	93 Mg; 6 Al; 1 Zn; 0.3 Mn	270	195	—	Parts subject to medium to high stress Precipitation hardened Complex diecastings Chips are combustible
GK-MgAl9Zn1wa	90 Mg; 9 Al; 0.6 Zn; 0.2 Mn	240	150	80	
GD-MgAl9Zn1	90 Mg; 9 Al; 0.6 Zn; 0.2 Mn	200	150	50	
Titanium Alloy (DIN 17850, 17851, 17860 ... 17864), modulus of elasticity $E \approx 110,000$ N/mm <sup>2</sup>					
Annealed titanium	99.7 Ti	290	180	—	Corrosion-resistant Corrosion-resistant, maximum strength
TiAl6V4F89	90 Ti; 6 Al; 4 V	890	820	—	

<sup>1)</sup> Tensile strength. <sup>2)</sup> Yield strength (0.2% offset). <sup>3)</sup> Rotating bending fatigue limit. <sup>4)</sup> Maximum. <sup>5)</sup> Strength values apply to permanent mold castings and die-castings for separately cast test specimens. Sand castings have slightly lower values than permanent mold castings <sup>6)</sup> Bending fatigue limit reversed bending stress.